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Investigation on Fresh Properties of Engineered Cementitious Composites (ECC)

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ملخص البحث
المركبات الأسمنتية الهندسية (ECC) عبارة عن بوليمرات مسلحة بالالياف ذات ممطولية عالية .يبلغ إجهاد الشد لـ ECCحوالي 200-500 مرة من الخرسانة العادية . هذه الممطولية الفائقة هي نتيجة للتحكم الكبير في انتشار الشروخ تحت قوى الشد الناتج من اضافه الألياف العشوائية .يهدف هذا البحث الى دراسة الخواص الطازجة للمركبات الهندسية الأسمنتية التي تحتوى على الرماد المطاير وخبث الافران .تم اختبار خلطات من مونة المركبات الاسمنتية الهندسية باستخدام نسب مختلفة من الرماد المتطاير وخبث الأفران. و تم استخدام اختبار الانسيابيه للمونة لدراسة الخصائص الطازجه للمركبات الاسمنتية الهندسية. ايضا تم استعراض نتائج الاختبار ومناقشتها وعرض الاستنتاجات والتوصيات.

Abstract
Engineered cementitious composites (ECC) are ultra-ductile fiber-reinforced composites. The tensile strain capacity of ECC is about 200-500 times that of ordinary concrete. This ultra-ductility is a consequence to the tight multiple cracking under tensile forces resulting from incorporating random micro-fibers. This paper investigates the fresh properties of Engineered Cementitious Composites incorporating fly ash and blast furnace slag. Six ECC mortar mixes, with different fly ash and blast furnace slag ratios were tested. The flow and rheological test was used for defining the characterizations of the fresh phase. The results of the experimental test will be presented and discussed in terms of initial flowability and flowability loss.

Keywords: fly ash, slag, flowability, FRC, HPFRCC, ECC.

1. Introduction
After many improvements of additions and admixtures, the application of dispersed fiber reinforcement results in a large variety of excellent building materials for different purposes – fiber reinforced cements and concretes (FRC). The main components are still Portland cement and coarse and fine aggregate of different origin, and there are several other components: super plasticizers, admixtures and micro fillers.

The term fiber-reinforced concrete (FRC) is defined by ACI 116R, Cement and Concrete Terminology, as concrete containing dispersed randomly oriented fibers. FRC usually exhibit strain-softening behavior, in which cracks open with decreasing traction. Although the material toughness is dramatically increased, the strain capacities of FRC compared to plain concrete remain at a low level. Moreover, workability is inevitably deteriorated due to the presence of fibers. In the past decade great strides have been made in developing high performance fiber reinforced cementitious composites (HPFRCC). HPFRCC is distinguished from an ordinary FRC by its unique macroscopic pseudo-strain-hardening behavior after first cracking when it is loaded under uniaxial tension.

Engineered Cementitious Composite (ECC) is a unique representative of the new generation of HPFRCC, featuring tremendous ductility and medium fiber content (Liu, Zhang et al. 2017). Material engineering of ECC is constructed on the paradigm of the relationships between material microstructures, processing, material properties, and performance, where micromechanics is highlighted as the unifying link between composite mechanical performance and material microstructure properties. ECC represents a design philosophy rather than a particular material.
However, in Egypt, there is still need to understand the fresh properties of engineered cementitious composites (ECC) incorporating high volume of cement replacement materials.

2. Materials and methods

2.1. Materials

The main ingredients used throughout this investigation are; Portland cement (PC), natural siliceous sand, polyvinyl alcohol (PVA) microfibers, fly ash (FA), and blast furnace slag (SL).

2.1.1. Ordinary Portland Cement (OPC)

A grade 52.5 PC is supplied from MISR BENI-SUEF CEMENT CO.; compatible with European standards (2004/1-197EN) and Egyptian standards (4756-1 /2007).

2.1.2. Fly ash (FA)

Type F fly ash is brought from CEMENTRAC Company for Cement Exporting complying with ES 7095/1-2009. The FA used in the study had a specific surface area of 3330 cm^2/g. The specific gravity of the FA was 2.15.

2.1.3. Blast-furnace slag (SL)

Blast-furnace slag used in this experimental program was also supplied CEMENTRAC Company for Cement Exporting complying with EN 15167/1-2006. The specific gravity of the GGBS was reported as 2.91 with a specific surface area of 3070 cm^2/g.

2.1.4. Polyvinyl Alcohol Fiber

Specimens made of ECC are reinforced with 2% by volume of polyvinyl alcohol (PVA) fibers which is equivalent to 26 kg/m^3. The properties of fiber are listed in Table 1.

Table 1: Properties of fibers

Cut length	Shape	Diameter	Tensile Strength	Modulus strength	Elongation at break
9 mm	Monofilament	15.33um	1620MPa	34GPa	6.8%

2.1.5. Water and High Range Water Reducer

A normal tap water is used for mixing and curing of specimens. A polycarboxylic High range water reducer (HRWR) from BASF Construction Chemicals (Master Glenium RMC 315) complying with BS 5075 Part 3 and EN934-2 is used. The objective of adding HRWR is to adjust the workability within an adequate range that provides well-dispersed fibers.

2.2. Method

2.2.1. Mixing proportioning

Based on the previous research works done over the last three decades; six mixes have been chosen to be tested. As shown in Table 2; three mixes incorporated FA, and the other three included FA with SL replacement. For all the tested mixes, the total binder content for one meter cube of concrete was 1190 Kg. The fly ash content ranged from 30% to 70% and the slag content was 10% to 30%. The water to binder ratio (w\b) and sand to binder ratio are kept constant for all mixes at 0.32 and 0.8 respectively. HRWR is add with dosage 1.2% by weight of cementitious materials for the FA mix and 1% for the FA-SL mix to keep the flowability within range 50-60%.

Table 2: Mixing proportions expressed in weight ratios

Mix No.	Cement	FA	SL	Water	Sand	HRWR
Mix 1	0.7	0.3	-----	0.32	0.8	0.012
Mix 2	0.4	0.6	-----	0.32	0.8	0.012
Mix 3	0.3	0.7	-----	0.32	0.8	0.012
Mix 4	0.3	0.6	0.1	0.32	0.8	0.01
Mix 5	0.3	0.5	0.2	0.32	0.8	0.01
Mix 6	0.3	0.4	0.3	0.32	0.8	0.01

Note: the fiber content was constant for all the tested mixes (26 Kg/m^3)

2.2.2. Mixing technique

The mixing process is performed in accordance with the method described by Zhou, Qian et al. 2012, aiming to improve the fiber dispersion in ECC. The mixing is conducted by a locally manufactured mixer with an electric motor of four horsepower. It offers the possibility to mix in two opposite rotation directions with velocity varying from 600 to 4000 revolution per minute. The mortar was mixed until homogeneity according to the sequence as follows. First, all the binder materials – cement, fly ash, and slag – are dry mixed for four minutes. Then, the sand was added and all the solids are mixed until homogenization. Next, proper amount of solids were first mixed with a reasonable part of the mixing water for two minutes at low speed. PVA fiber and HRWR were added and mixed for two minutes at low speed, and one minute at high speed until achieving apparent full fiber distribution. After that, the rest of solid materials and mixing water are added and mixed for two minutes at low speed and two minutes at high speed. Finally the mortar is manually mixed to assure homogeneity.

3. Test set-up of fresh properties for mortar mixes

The flowability test is used to illustrate the consistency and rheology of fresh concrete to measure the flowability and rate of flowability loss, Figure 1. The purpose of this test is to indicate the effect of different replacement materials with different replacement ratios on workability of ECC. The flowability test is conducted immediately after finishing mixing process using a brass cone mold with dimensions in accordance with ASTM C1437 for determining flow of hydraulic cement mortars, Figure 2.

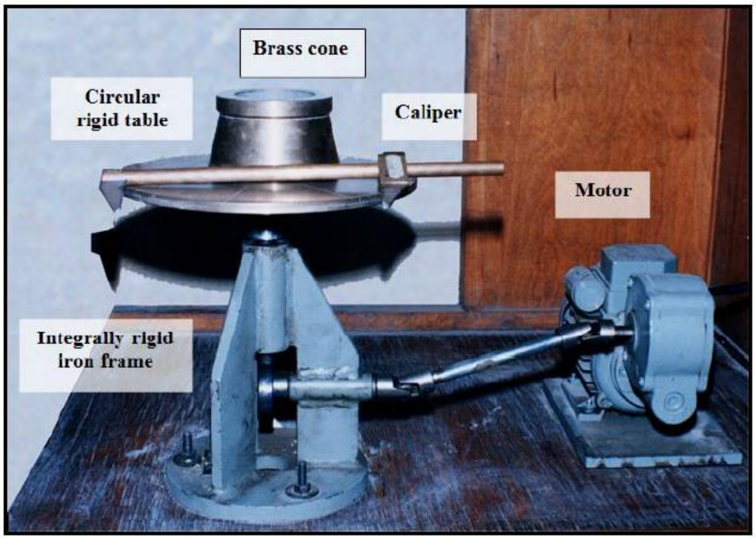


Figure 1: Geometry of cone mold for flowability test

The test methodology includes the following steps:

1. Place the cone mold on the center of the circular rigid table.
2. Fill the cone by pouring the mortar on two layers and tamp each layer twenty times then plane the surface of mortar with the top of mold.
3. Lift the cone up and drop the table twenty five times
4. Measure the diameter of the spread mortar.

Figure 2: During conducting flowability test

Fresh mortar and concrete are considered visco-plastic materials that do not follow newtonian behavior as they have yield stress (Banfill 2014). Studying of mortar's rheology is important for evaluating ease of placement, consolidation, durability, and strength (Ferraris 1999). It includes determining two main parameters; the yield stress and plastic viscosity which were defined in the Bingham equation (Banfill 1991). The yield stress is the stress beyond it; the mortar becomes a fluid and the plastic viscosity is a measure of how easily the mortar will flow after yielding. A lot of tests and models have been set for evaluating rheology of fresh mortars such as: One-Factor Tests, Slump Test, Penetrating Rod: Kelly Ball, Vicat, and Wigmore Tests, Turning Tube

Viscometer, K-Slump Test, Ve-be Time And Remolding Tests (Powers Apparatus), LCL Apparatus, Vibration Testing Apparatus and Settling Curve, Fritsch Test, The flow cone, Orimet Apparatus, Two Factor Tests, Tattersal Two-Point Test, Bertta Apparatus and The BTRHEOM Rheometer (Ferraris 1999). Here, we used the flow table apparatus and applied certain number of blows (0, 3, 6, 9, 12, 15, 18, 21 and 25) and the spread of mortar at each level is recorded.

4. Test Results and Discussion

The fresh properties considered in this study were investigated from the results of the flow test. The initial flowability (just after mixing), the flowability loss rate and the effect of different CRM ratios were evaluated. The fresh properties considered in this study were investigated from the results of the flow test. The initial flowability (just after mixing), the flowability loss rate and the effect of different CRM ratios were evaluated.

4.1. Flowability

The effect of FA and SL contents on the initial flowability of ECC mortars is clarified in Figure 3. Each result represents an average of four readings. The results revealed that the increasing the FA content has a positive effect on the initial flowability. This is attributed to the spherical shaped particles of fly ash that act as miniature ball bearings within the concrete mix, thus providing a lubricant effect. However, increasing the SL content had a very little negative effect on the initial flowability.

The rate of flowability loss of the mortars is evaluated by monitoring the instant flowability at different elapsed periods from finishing the mixing till 90 min. The relative flowability values (the percentage of instant flowability to initial flowability) against the time from mixing are plotted.

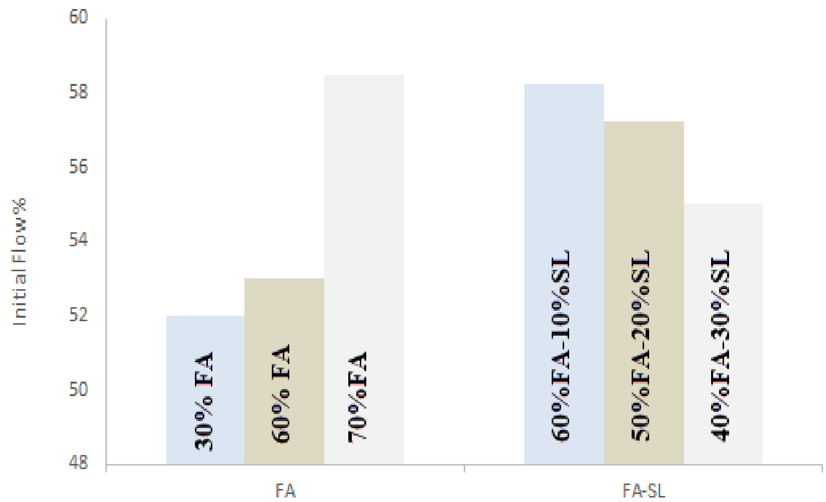
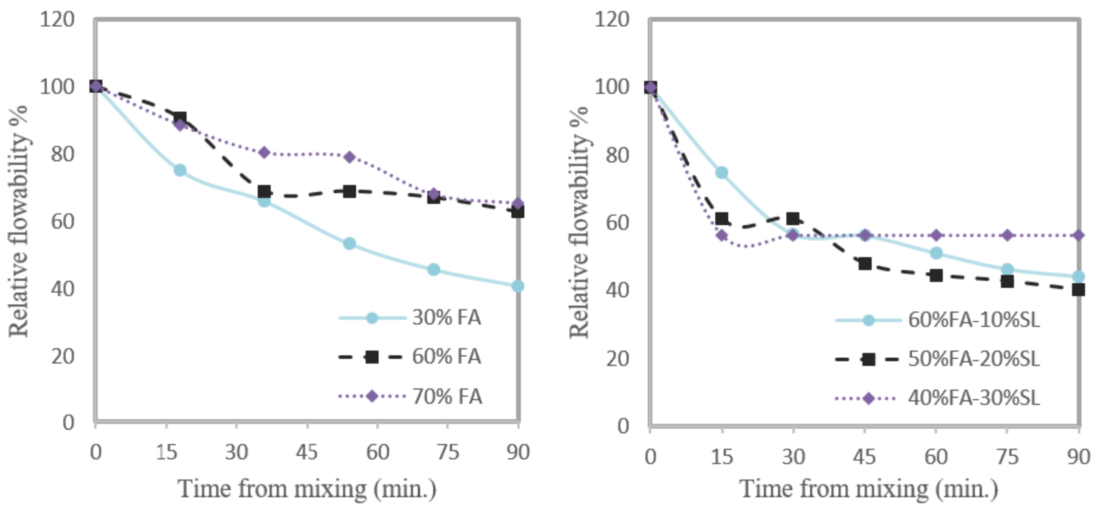


Figure 3: The initial flowability values for the ECC mixtures

It is obvious in Figure 4; that by increasing the time elapsed from mixing; the relative flowability decreases. For the mixtures with FA replacement Figure 4.a; the rate of flowability loss decreased with increasing the replacement ratio. Furthermore, rapid flowability loss is noted by increasing SL content, Figure 4.b.



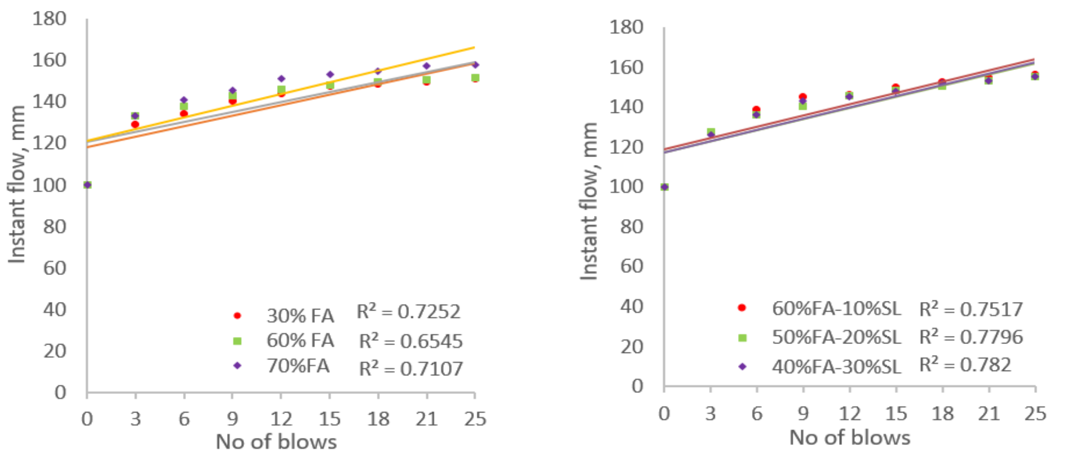
(a) (b)

Figure 4: Flowability loss for ECC mixes, (a) FA replacement and (b) SL replacement.

4.2. Rheology

The relationship between the number of blows and the corresponding instant flowability are plotted in Figure 5. The results showed a direct proportional relation between the no. of blows (the external applied stress) and the instant flowability of mortar. At number of blows equals zero there was no change in the instant flow. This may be attributed to the low w/c and the presence of PVA fiber which does not allow the mortar to flow without external effect.

It is noticed that the trend line of each of the plotted curves simulates the Bingham's material model, Figure 6. It could be considered that the intersection with the number of blows is the externally applied stress (S_y), the vertical axis (instant flow) represents the yield stress and the slope of the trend line (ϴ) represents the plastic viscosity (μ). The measured values of the slope and the intersection with the vertical axis are giver in Table 3.



(a) (b)

Figure 5: Number of blows against instant flowability, (a) FA replacement, (b) FA-SL replacement

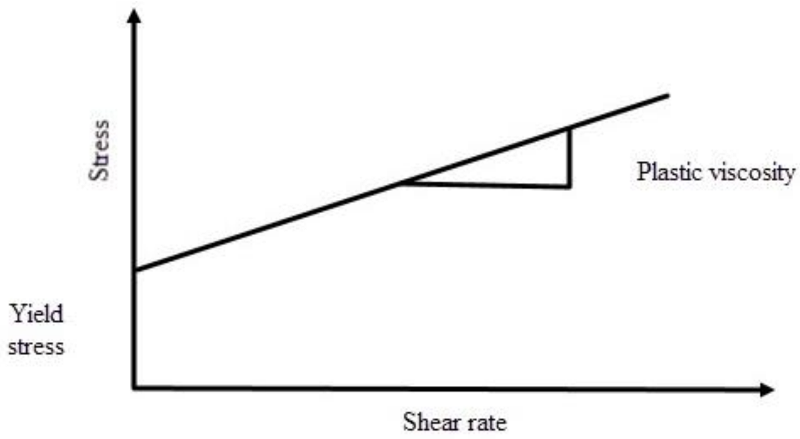


Figure 6: Bingham's equation for a fluid (Ferraris 1999)

Table 3: Values of the slope, R2 and the intersection with the instant flowability axes

Mixture	R^2	Slope (ϴ)	intersection
30% FA	0.72	5.033	113.25
60% FA	0.65	4.8	116.08
70%FA	0.71	5.641	115.63
60%FA-10%SL	0.75	5.63	113.06
50%FA-20%SL	0.78	5.58	111.76
40%FA-30%SL	0.78	5.63	111.56

A notable reduction in the plastic viscosity (slope) was recorded at mixture (60% FA). It is clear that adding replacing Portland cement with FA and SL affect the rheology of the produced mortar. It should be mentioned that further studies are needed to measure exact S_y and μ for better understanding of the rheology of the used mixtures.

5. Conclusion

This paper studied different CRM ratios (fly ash and slag) to evaluate the fresh properties of ECC. Incorporation FA resulted in enhancement in initial flowability. However, increasing the slag content had a negative effect on flowability.

6. Recommendation

This investigation is limited to the fresh characteristics of ECC. In the future, further tests should be conducted for better understanding of the mechanical and microstructure properties of ECC.

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